

# Wacky Racers 2021 Instructions

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## 1 Introduction

The purpose of this assignment is to design, build, and program an embedded system using an ARM microcontroller and surface mount technology.

The goal for each group of four students is to build a remote controlled vehicle (the Wacky Racer) and its controller (the Wacky Hat). At the conclusion of the assignment there will be a dastardly race!

Each group is comprised of two sub-groups of two students. One of these subgroups constructs the Wacky Racer and the other constructs the Wacky Hat. You may be asking why is the Wacky Hat called the Wacky Hat? Well, a hat that controls a remote vehicle using head motions is not an ordinary hat!

## 2 Requirements

The following requirements are mandatory if you wish to maximise your marks.

### 2.1 Wacky racer

1. The chassis is to be constructed by each group. These can be 3-D printed, constructed from Perspex or wood, etc. A standard chassis is available from the Automation Lab technician (Daniel Hopkins). The electronics must be visible on top of the chassis.
2. Have a standard working bump sensor (supplied).
3. Locomotion can only use two 6 V DC motors (supplied).
4. Everything must be powered from a single 5-cell NiMH battery pack (supplied).
5. Use a single four layer printed circuit board of dimension 85 mm×64 mm.
6. Use an ARM microcontroller (Atmel SAM4S8).
7. Drive the motors using H-bridges (Texas Instruments DRV8833 dual H-bridge is recommended).
8. Regulate the nominal battery voltage to 5 V with a buck regulator IC (ADP2302ARDZ-50).
9. Be decorated with an LED tape (supplied) controlled by the MCU.
10. Use a USB interface for debugging.

11. Use a serial wire debug interface for MCU programming/debugging.
12. Have adequate battery fusing and reverse polarity protection.
13. Have a sleep button.
14. If the battery voltage drops below 5 V, an LED should flash and high power draw devices should be disabled.
15. Interface to the Wacky Hat with a Nordic nRF24 SMD radio module.
16. Have four jumper selectable radio channels.
17. Have a mounted RFID card (supplied) that can be read by the Wacky ramps.
18. Be humorous.

Each Wacky Racer can have a dastardly means of hindering another team's Wacky Racer. However, you cannot:

- Damage or destroy another Wacky racer
- Damage the venue
- Injure a spectator
- Jam the radio signals

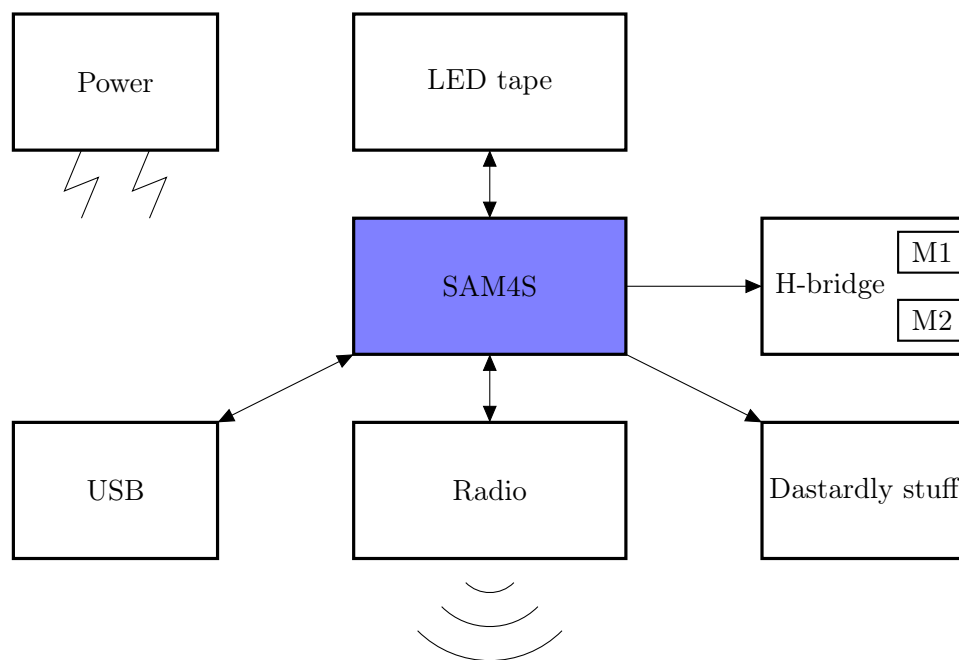


Figure 1: Racer board top level diagram.

## 2.2 Wacky hat

1. Construct a Wacky Hat that contains all the electronics.
2. Everything must be powered from a single 5-cell NiMH battery pack (supplied).
3. Have adequate battery fusing and reverse polarity protection.
4. Use a single four layer printed circuit board of dimension 85 mm×64 mm.
5. Use an ARM microcontroller (Atmel SAM4S8).
6. Regulate the nominal 6 V battery voltage to 5 V with a buck regulator IC (ADP2302ARDZ-50).
7. Be decorated with an LED tape (supplied) controlled by the MCU.
8. Use an I2C IMU (MPU-9250) for head motion detection.
9. Use a USB interface for debugging.
10. Use a serial wire debug interface for MCU programming/debugging.
11. Have a joystick in case the IMU does not work.
12. Have a sleep button.
13. If the battery voltage drops below 5 V, an LED should flash and high power draw devices should be disabled.
14. Play sound when the bumper is hit.
15. Interface to the Wacky Racer with a Nordic nRF24 SMD radio module.
16. Have four jumper selectable radio channels.
17. Be humorous.

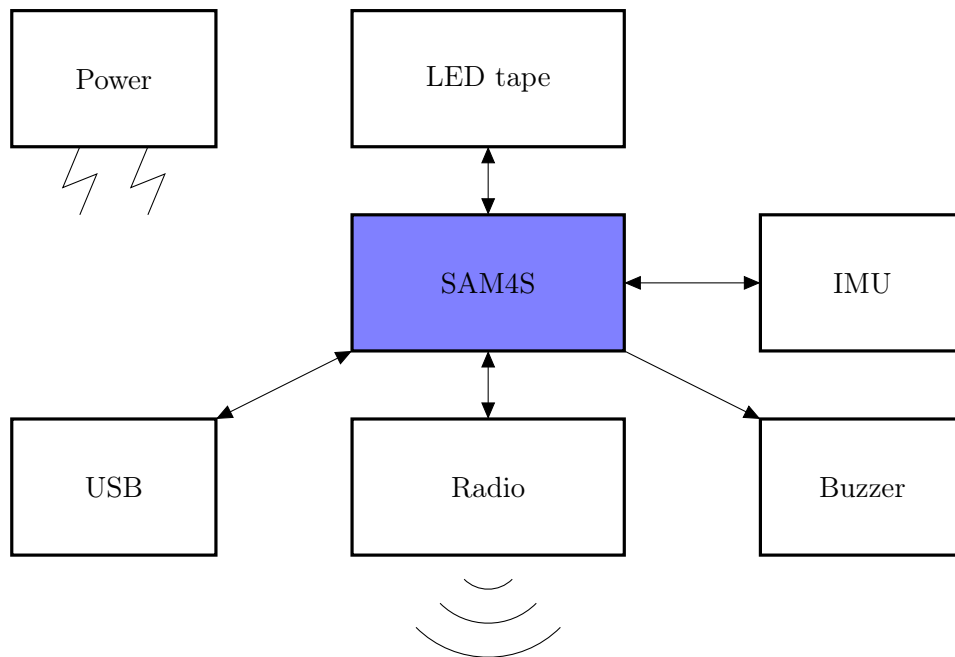


Figure 2: Racer hat top level diagram.

### 3 Assignment schedule

The planned activities for the timetabled labs in the Embedded Systems Lab (ESL) are:

Week	Assistance	Assessment
T1-1	Altium tutorial 1 (schematics)	Schematic submission for review (Friday 5pm)
T1-2	Altium help	
T1-3	Schematic review	
T1-4	Altium tutorial 2 (PCB)	PCB submission 1
T1-5	Altium help	
T1-6	Altium help	
B-1	(break)	PCB submission 2
B-2	(break)	
B-3	(break)	
T2-1	General	Blinky
T2-2	General	
T2-3	General	
T2-4	General	IMU/motors
T2-5	General	Radio control
T2-6	General	Functionality
T2-6	Competition	Competition, critique

Notes:

1. There may be a 6–10 day delay for the PCBs to be manufactured from the time of submission. You will then need to book an assembly session in the SMT lab provided you have done the SMT lab induction.
2. Do not underestimate the blinky milestone. It requires having a functional PCB with a microcontroller that turns on properly, a functional toolchain and the ability to download code into the microcontroller's flash memory.

### 4 Assessment

The marks breakdown (max. 0x64) is:

PCB submission	0–0xa marks
Blinky milestone	0x5 marks
IMU/motor milestone	0x5 marks
Radio control milestone	0x5 marks
Functional assessment	0–0x14 marks
Board inspection	0–0x1e marks
Competition	0–0xa marks
Individual critique	0–0xf marks

#### 4.1 Milestones

There are five milestones. To achieve the associated marks, they must be demonstrated to a T.A. by the end of the lab for your allotted stream. If you need an exception to this, see Ben Mitchell with a *very* good reason. The milestone requirements are:

**Schematic review** Submit your A3 schematic on Learn for review. Lose 10 marks if you miss the submission time.

**PCB submission** Submit your PCB design to Learn for manufacture. To encourage early submission there is a sliding scale for marks depending on when the PCB is submitted, see table. After week 6, there is a 10 mark penalty per week. **NB, a rushed PCB design will cause you more grief, more PCB rework, and a lower mark for the inspection.**

Week	Submission day	Cut-off time	Mark
5	Monday	10.00 am	10
5	Tuesday	10.00 am	9
5	Wednesday	10.00 am	8
5	Thursday	10.00 am	7
5	Friday	10.00 am	6
6	Monday	10.00 am	5
6	Tuesday	10.00 am	4
6	Wednesday	10.00 am	3
6	Thursday	10.00 am	2
6	Friday	10.00 am	1

**Blinky** Demonstrate that can blink an LED controlled by the SAM4S.

**IMU/motors** For the Wacky Hat, demonstrate output of IMU readings to a PC using USB CDC. For the Wacky Racer, demonstrate control of the motors from a PC using USB CDC.

**Radio control** Demonstrate sending commands from the Wacky Hat to the Wacky Racer over a radio link.

**If you cannot show the functionality of a previous milestone during any assessment, you will fail that assessment and loose any marks from the previous milestone.**

## 4.2 Functionality assessment

Functionality requirements:

Wacky racer	Wacky hat
Blink LED	Blink LED
Drive motors forward/backward	Read from IMU
Speed control of motors	Calculate speeds from IMU
Steering control	Joystick control
Receive radio message	Send radio message
Jumper selectable radio channel	Jumper selectable radio channel
Dies on bump	Plays sound on bump
Low voltage indication	Low voltage indication

Marks are allocated on how well things work. Up to 5 bonus marks can be awarded for extra functionality such as:

Wacky racer	Wacky hat
Dastardly stuff	Plays interesting sounds
Sleep mode	Sleep mode

### 4.3 Competition

The competition is a race around an obstacle course. Marks will be awarded every time you pass over a Wacky Ramp in the correct order. These ramps have an RFID card reader that will detect your Racer if you have correctly fitted an RFID card. The Wacky Ramps change colour when they detect a Wacky Racer.

To be awarded any marks for the race:

1. Your vehicle must stop for at least 5 s if the bumper is hit.
2. Your vehicle must be controlled by motions of the Wacky hat sitting on someone's head.

### 4.4 PCB inspection

This is assessed after the competition. The categories are:

1. Layout (component placement etc.)
2. Construction (tidiness, rework, etc.)
3. Testability
4. Power supplies (routing, decoupling, etc.)

## 5 Technical stuff

Read this section carefully. There are clues as to how we mark your PCBs at the end of the assignment.

### 5.1 External components

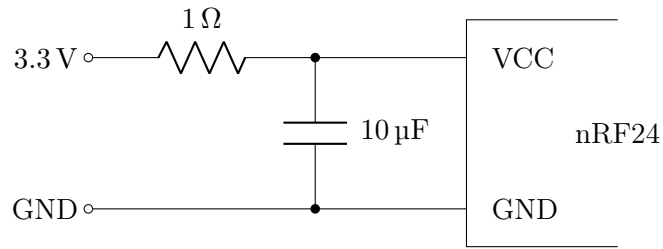
#### 5.1.1 Battery

The battery we provide for the assignment is a 5-cell NiMh battery with a *nominal* voltage of 6.0 V. This battery uses a standard RC servo connector: 3 pin 0.1" (pin 1 GND, pin 2 5V, pin 3 NC). We suggest connecting both the first and third pins to ground to allow the battery to be plugged in in both orientations. The 461 Altium library has a component named 'Battery\_HEADER\_3pin' that is suitable to use.

#### 5.1.2 Radio

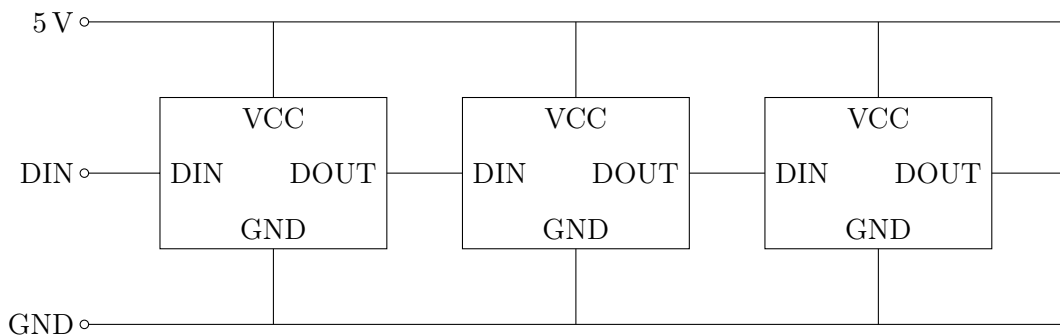
The nRF24 module we provide is actually a tiny PCB with all of the high frequency analogue components populated for you. This module breaks out the SPI communication pins, the power supply pins, and two signal pins that you will need to connect to your microcontroller. The CE and IRQ pins can both go to general PIO pins while the SPI pins (MOSI, MISO, SCLK, CSN) need to be connected to the SAM4S SPI peripheral.

As this radio is ultimately an analogue circuit and any noise on the power supply can affect the signal quality, we recommend using a separate 3V3 regulator and using a low pass filter to provide the best power.



### 5.1.3 LED Tape

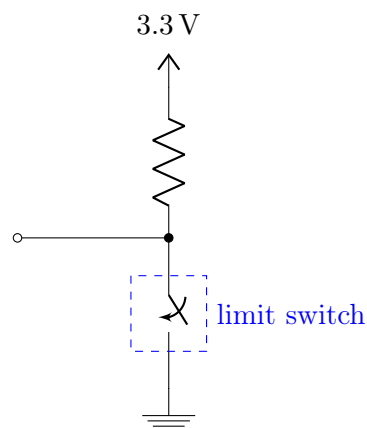
The LED tape is a string of WS2812 LEDs connected in a line. These LEDs use a clever mechanism to pass the RGB data down the string. They are connected in series like:



This means you will need to provide a three pin header (0.1" standard header) with the pinout: pin 1 5V, pin 2 signal, pin 3 ground. Each individual LED has a maximum supply current of 60 mA (20 mA per red, green, blue channel). We will provide up to half a metre of LED tape to each car or hat, giving a maximum number of 30 LEDs to be driven.

### 5.1.4 Bumper

The provided bumper senses the contact through a simple limit switch. This switch is normally open and on contact will close.



Note that the pullup resistor shown could simple be the internal pullup resistor on a PIO pin. The connector for the limit switch should be a simple 2 pin 0.1" header.

### 5.1.5 Buzzer

The buzzers supplied are passive piezo-electric devices. Applying a voltage across the two terminals causes the element to deform. Applying an alternating current to the device generates an audible tone. The larger the applied voltage differential, the louder the tone becomes. There are plenty of example circuits for piezo buzzers available online.

### 5.1.6 Motors

The motors available in the provided chassis are 6 V DC motors. These have a low DC resistance and will take as much current as the DRV8833 motor driver can supply. You need to add connectors for the motors, either 2 pin 0.1" headers or screw terminals are suggested.

## 5.2 Version control

Use version control for everything, or else! Learning git is frustrating but is a skill you will not regret.

Your group leader should create a forked copy of the wacky-racers git project and then add the other group members to the project. This can be done by:

1. Go to <https://eng-git.canterbury.ac.nz/wacky-racers/wacky-racers>
2. Click 'Fork' button. This will create a copy of the main repository for the project.
3. Click on the 'Settings' menu then click the 'Expand' button for 'Sharing and permissions'. Change 'Project Visibility' to 'Private'.
4. Click on the 'Members' menu and add group members as Developers.
5. Using a bash terminal (or other useful shell), enter the command:

```
$ git clone https://eng-git.canterbury.ac.nz/your-userid/wacky-racers.git
```

If you do not want to have to enter your password for every git push/pull operation, you should set up ssh-keys and use the git URL instead:

```
$ git clone git@eng-git.canterbury.ac.nz:your-userid/wacky-racers.git
```

6. Add a remote URL for the main repository.

```
$ cd wacky-racers
$ git remote add upstream https://eng-git.canterbury.ac.nz/wacky-racers/wacky-racers.git
```

Again if you do not want to manually enter your password, you can use:

```
$ cd wacky-racers
$ git remote add upstream git@eng-git.canterbury.ac.nz:wacky-racers/wacky-racers.git
```

7. If we add more demo code or tweak the instructions in the main repository, you can get the updated stuff using:

```
$ git pull upstream master
```



### 5.3 Components

1. We recommend that you use components in the ECE Altium library. These are stocked in the SMT lab. For any other components you may require, see Scott Lloyd in the SMT lab.
2. The Wacky Racer batteries are Turnigy 5-cell 6 V, 2300 mAh, NiMH with a three pin JST connector. To preserve the battery life it is imperative to not draw current when the battery voltage is below 5 V. Note, when fully charged, the battery voltage may be 7.5 V.

### 5.4 Connectors

1. USB micro or mini connector for debugging
2. 3 pin 0.1" for LED tape (pin 1 5 V, pin 2 signal, pin 3 ground)
3. 2 pin 0.1" for bumper (pin 1 switch, pin 2 ground)
4. 10 pin IDE for serial wire debug
5. 3 pin JR battery connector (pin 1 GND, pin 2 VBAT, pin 3 GND)
6. motor connectors (for Racer)
7. connectors for dastardly stuff

### 5.5 Schematics

1. Have a look at the Altium tutorial on ecewiki.
2. Have a read of the schematic guidelines on ecewiki.
3. Add you and your partner's name and your group number to the title block on your schematic.
4. Save PDF files of your schematics in your source repository. **Note, when debugging your PCBs, we will not help you until you show us your printed A3 schematic.**
5. We bet that you will not have enough test points to clip an oscilloscope probe to. Do not think you can hold the probe tip against an MCU pin. Ensure you give a meaningful name to the test point in its comment field. A ground test point is essential for an oscilloscope earth clip. Keep this clear of other test points since the clip may short against them. You will probably require at least two ground points.
6. Checking the schematic is the most crucial part of the assignment. If the schematic is wrong then your PCB will be wrong. So, schematics must be thoroughly checked by another person.
7. Consider fall-back options if you have a problem with your PCB.

The IMU for the Wacky Hat is tiny and we **strongly recommend** that you provide an alternative connector for connecting the following IMU module: MPU-9250 on AliExpress

Similarly for the Wacky Racer, in case the H-bridge fails, provide two three-pin servo connectors so that external Electronic Speed Controllers (ESC) can be used to drive the motors.

8. It would be useful to have a jumper or two connected to a PIO pin so that you can configure your board. For example, if a jumper is in, use the joystick, otherwise use the IMU.

## 5.6 PCBs

1. Your four-layer PCBs are going to be manufactured in batches. There is at least a week turnaround time to get the boards made.
2. It is important that you check footprints for parts they you create. We will impose a 10% penalty for each rerun of a PCB, say due to a footprint mistake. Get your partner to check.
3. Turn of the test point designators and turn on comments instead. This lets you give them human readable names to make your lives easier.
4. PCB layouts must be thoroughly checked by another person.
5. A PCB track can blow faster than a fuse. So keep high current tracks fat and short.
6. Clearly mark the positive and negative battery connections on the silk screen.
7. Some of the chips can get hot so thermal considerations are required. Follow the manufacturers' guidelines in the datasheets.
8. The switching regulators can interfere with the radios.
9. Use a design rule check to see if any of the following constraints are violated:
  - Minimum trace width (0.15 mm)
  - Minimum trace clearance (0.15 mm)
  - Minimum via size (0.3 mm hole, 0.6 mm outer diameter)
  - Minimum hole size (0.3 mm)
  - Minimum annular ring (0.1 mm)

For every violation of one these rules, we will deduct 1% from your final mark.

10. Check the PCB checklist on ecewiki before submission.

## 5.7 Assembly

1. Finding shorts is extremely frustrating so maximise clearances and test for shorts before populating components.
2. Components can be put through the oven on the reverse side although heavy components may need to be glued.
3. Never assume where pin 1 is on an IC; check the datasheet. 5–10% of groups will get this wrong.

## 5.8 Software

1. We highly recommend using a personal laptop with Linux installed if possible. A virtual machine running Linux on Windows is acceptable for this. You will need to check instructions on ecewiki for how to install the required toolchain. We advise against using the

Windows Subsystem for Linux, rather it is much simpler to fix issues when you just use an actual Linux.

2. Development on Windows is now possible thanks to Philipp Hoff, however, neither MPH, nor Ben can help with debugging the Windows toolchain.
3. If you are not using version control for this you are foolish.
4. Inspect MPH's sample code.

## 5.9 Programming

1. If you are trying to program the SAM4S for the first time and are feeling tired or impatient, then do something else.
2. For the first program, do not use batteries or a USB connection. The ST-Link adapter will provide 3.3 V to the MCU.
3. Detailed instructions can be found at [http://ecewiki.elec.canterbury.ac.nz/mediawiki/index.php/Wacky\\_racers\\_software](http://ecewiki.elec.canterbury.ac.nz/mediawiki/index.php/Wacky_racers_software).

## 5.10 Debugging

1. Start running small programs (such as the provided demo programs) to test each feature separately.
2. An oscilloscope is your friend.
3. It is possible to use the GDB debugger but you need to know what you are doing, especially with optimised code.
4. Drawing a diagram of what you think is happening is highly recommended. A simple circuit diagram or timing diagram will often help you realise what you have missed and let you fix it without asking for help.

## 5.11 Possibly asked questions with answers

- *Why use the SAM4s MCU?* For this application most MCUs would suffice, even an 8-bit AVR microcontroller. To level the playing field, I have chosen a MCU most students would not have used before. This is an ARM based MCU made by Atmel I have used this in a number of projects. Indeed we used to teach this chip in ENCE361. There are many other similar MCUs made by different manufacturers such as the STM32 that would just as suitable.
- *Why use a four layer PCB?* Come to lectures to find out!
- *Why use 7.2 V NiMH batteries for the Wacky Racers?* These were a legacy of previous Wacky Racers. They are also safer than lithium batteries with sleep-deprived students.

## 6 Assistance

- Emails to the lecturers (except of a personal nature) will be quietly ignored.

- Questions answered on the ENCE461 Learn discussion page will be promptly answered.
- All decisions regarding legality of your dastardly devices are at the whim of Ben Mitchell. You can email Ben at [ben.mitchell@pg.canterbury.ac.nz](mailto:ben.mitchell@pg.canterbury.ac.nz) if you wish to keep your ideas secret.
- TAs will be available in the scheduled lab times. Priority will be given to groups assigned to the current lab session. **We will only provide assistance to students who have a printed A3 schematic sheet in front of them and have already tried looking up the problem on <https://ecewiki.elec.canterbury.ac.nz>.**
- Questions pertaining to Altium and surface mount rework will be answered by Scott Lloyd (SMT Lab technician) and Diego Ramirez (Electronics Lab technician).
- Michael Hayes is really busy pulling all the string behind the scenes and so will only help with gnarly problems referred to by the TAs!